

The present invention relates to electric power plant boilers and more particularly to those using solid fuels containing carbon materials.

5        In general, this type of boiler uses air as the oxidizer. This technology is proven, but it must contend with the new requirements to capture CO<sub>2</sub> in the flue gases issuing from the combustion of these carbon materials before release into the atmosphere.

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The CO<sub>2</sub> present in the flue gases can obviously be selectively extracted, but because of their low content (15% by volume), this postcapture proves to penalize efficiency and is extremely costly.

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To decrease the quantity of CO<sub>2</sub> produced, it is known from the proprietor's patents US 6 202 574 and US 6 505 567 to carry out the combustion using oxygen, no longer diluted in nitrogen as in the air, but oxygen  
20        diluted in recycled CO<sub>2</sub>. The boiler thereby only produces a gas stream of CO<sub>2</sub> and water vapor, which can be dried and liquefied for transport to a subsequent use of the CO<sub>2</sub> or for underground sequestration.

25        In this case of O<sub>2</sub>/CO<sub>2</sub> combustion, the step of selective extraction of the CO<sub>2</sub> present in the flue gases, which involves high energy consumption, is eliminated, but a new energy penalization appears, deriving from the electric power consumption associated  
30        with the cryogenic production of oxygen, which is the only method available today for producing large quantities of oxygen. The power consumption due to oxygen production is so high as to risk making the oxycombustion technology economically prohibitive.

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The high temperature oxygen transport membranes available today are suitable for extracting oxygen from the air. They are used to feed burners like, for example, those described in patent application

WO02/077419 or the patents US 6 539 719 and US96 562 104. However, these membranes can only be used in gas medium. Moreover, the oxygen issuing from the membrane must be flushed with an auxiliary gas.

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It is the object of the present invention to propose a boiler using oxygen as oxidizer, which offers high efficiency, is highly compact, and at relatively reasonable cost.

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The boiler of the invention has a circulating fluidized bed, uses solid fuels and the oxygen obtained by high temperature oxygen production membranes, and is characterized in that the membranes are placed in the bed. These membranes are, for example, of the OTM (Oxygen Transport Membranes) type. Since the membranes operate at over 700°C (between 700 and 1000°C), their positioning in the outer bed is ideally selected because the temperature of the solids circulating in the outer bed is between 750 and 900°C. This is particularly remarkable because the operating temperature windows of the circulating fluidized bed coincide with the optimal temperature window of use of the membranes.

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According to a first feature, the membranes are traversed by pressurized air. To facilitate the extraction of the air from the membranes, it is slightly pressurized. The air issues from a blower or a compressor, which generates a pressure higher than that prevailing in the fluidized chamber.

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According to one particular feature, the membranes are placed in the fluidized solids of the outer bed. The hot solids withdrawn from the main loop of circulating solids provide the heat input to maintain the membranes at the optimal operating temperature, and they ensure the removal of the oxygen from the outer wall of the membranes. The solids also ensure

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excellent thermal contact with a very high flow of materials flushing the outer walls of the membranes at the proper temperature, thereby improving the oxygen transfer kinetics compared with an exchange on gas alone. Since the heat exchange takes place with solids and not with gas, the membrane area necessary can be lower, which is essential for the compactness and economics of the technology. The possible adjustment of the flow of solids to the membranes allows the adjustment of the temperature of the chambers of the outer bed.

According to another feature, the membranes are placed above the fluidized solids of the outer bed. In this case, the outer bed serves to heat the gas such as recycled  $\text{CO}_2$  used to fluidize the bed and which then provides the heat input and ensures the removal of the oxygen. The two membrane installations can be advantageously combined in the solids and above the solids.

According to a particular arrangement, the membranes are placed on at least part of the periphery of the perimeter of the lower firebox. This arrangement allows for the possibility of additional membrane areas.

According to another particular arrangement, the membranes make up an assembly resting on the hearth of the firebox. Since the hearth is fluidized by recycled  $\text{CO}_2$ , the membranes can be placed on the hearth of the firebox because the stiffness of the hearth reduces the mechanical stresses on the tubes, thereby allowing the use of long lengths.

According to a first variant, the membranes consist of very long tubes supported by intermediate plates. The intermediate tubesheets may or may not be cooled with inlet and outlet chambers.

According to a second variant, the membranes consist of short tubes with intermediate chambers. The tubes can be arranged in series or in parallel.

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According to a third variant, the membranes consist of concentric tubes of which the inner tube serves as support for the outer membrane tube. The inner tube is sufficiently stiff to ensure the mechanical strength of the membranes. The inner tube comprises openings so that the oxygen of the air can pass through the membrane tube placed above, and is sufficiently stiff to improve the mechanical strength of the membranes.

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According to a particular arrangement of the third variant, a space is provided between the two tubes. A spacer is placed between the two tubes in order to secure the outer tube. It is traversed by air either in the same direction as the stream in the annular space, and in this case, it comprises openings for communication of the air from the inner tubes to the annular space, or in countercurrent flow, with communication at the end of the tube, and in this case, it does not comprise openings along its length.

According to another arrangement of the third variant, the air is in countercurrent flow in the space between the two tubes. In this case, the two tubes do not have openings along their length, but communicate via their end. The air hence traverses the first inner tube from end to end, then passes into the intertube space and re-traverses the intertube space in the opposite direction. The advantage of this solution resides in the fact that the air is in direct contact with the membrane along the whole length of the outer tube and not only opposite the openings.

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According to another arrangement, a dense

fluidized bed is placed along the inside walls of the firebox. In this configuration, the feed to said dense fluidized bed containing the membranes by descending solids collected along the walls of the firebox tends  
5 to improve the performance of the boiler at partial load and to reduce its minimum load, because there is no longer any need to rely exclusively on solids withdrawn from the outer flow, which varies considerably according to the load of the boiler,  
10 particularly at low load, providing an economic advantage for the operator. The capture zones of the dense bed can directly accommodate the membrane tubes from which the escape of  $\text{CO}_2$   $\text{O}_2$  is directly integrated in the firebox without connecting flues.

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According to another feature, the air traversing the membranes is conveyed to a waste heat boiler. The enthalpy of this oxygen-depleted air is recovered by said waste heat boiler, and the depleted air, cooled to  
20 low temperature (about  $80^\circ\text{C}$ ), being noncorrosive, is directly discharged to the atmosphere via the stack.

According to a supplementary feature, the depleted air waste heat boiler is combined, in a sealed manner,  
25 with a waste heat boiler for the flue gases leaving the firebox. The combination of the two waste heat boilers serves to make the installation more compact, but they are separated in a sealed manner so that only air is released to the atmosphere, while the  $\text{CO}_2$  is transferred  
30 to sequestration or storage. In fact, any nontightness between the two boilers decreases the purity of the  $\text{CO}_2$  by the introduction of nitrogen and oxygen, which may compromise the final use of the  $\text{CO}_2$ .

35 The invention will be better understood from a reading of the description that follows, provided exclusively as an example and with reference to the drawings appended hereto, in which:

- Figure 1 is a general view of a boiler of the invention,

- Figure 2 is a general view of a boiler with the variant of a bed placed in the firebox,

5       - Figure 3 is a detailed view of the bed with a first arrangement of the membranes,

- Figure 4 is a detailed view of the bed with a second arrangement of the membranes,

10       - Figure 5 is a detailed view of the bed with a third arrangement of the membranes,

- Figure 6 is a detailed view of a support tube with a membrane,

- Figure 7 is a detailed view of the bed with the membranes arranged above the solids of the bed,

15       - Figure 8 is detailed view of the bed with the membranes arranged both in and above the bed,

- Figure 9 is a detailed view of the firebox with membranes arranged in the bottom of the firebox,

20       - Figure 10 is a detailed view of the firebox with membranes arranged on the hearth of the firebox,

- Figure 11 is plan view of the hearth of the firebox in Figure 10,

- Figure 12 is a cross section of the third variant with a space between the two tubes,

25       - Figure 13 is a longitudinal section of the third version.

As shown in Figure 1, the fluidized bed boiler 1 comprises a firebox 2 and a cyclone or separator 3 for  
30 separating the solids present in the flue gases, a solids recirculation loop 4, a solids extraction 5 to a dense fluidized bed 6, called the outer bed, containing a set of membranes 7.

35       A line 30 conveys the flue gases issuing from the cyclone 3 to a waste heat boiler 8.

The outer bed 6 receives the solids 67 via the extraction line 5, and the solids are then reinjected

into the firebox 2 via the line 60. The bed 6 is fluidized by recycled CO<sub>2</sub> arriving via the line 61 and then exits via the line 62 for reintroduction into the firebox 2 by injectors 63 placed at several levels.

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The external air enters via a blower or compressor 70 and is sent to the bed 6 via the line 71, then passes through the membranes 7 to exit via the line 72, which sends the depleted air to a waste heat boiler 9, the air then being discharged into the atmosphere.

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We shall now describe the circulation of the air in the boiler 1 in Figure 1. The air arrives via the line 71 after having been pressurized by the blower 70, the pressure must be slightly higher than the pressure prevailing in the chamber of the bed 6 in order to promote the extraction of the oxygen from the air. The depleted air is sent via a line 72 to the waste heat boiler 9, where it is cooled and then released to the atmosphere.

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The solids are separated in the cyclone 3 and sent via the line 4 either to the bed 6 via 5, or via the direct return line 20 to the firebox 2. The solids reaching the bed 6 are cooled and reinjected into the lower part of the firebox 2.

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The bed 6 is fluidized by gas such as recycled CO<sub>2</sub> arriving via the line 61, this fluidization gas is mixed with the oxygen produced by the membranes 7 and is then conveyed to the lower part of the firebox 2 via the lines 62.

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In the variant shown in Figure 2, a dense fluidized bed 6a is placed in the bottom of the firebox 2, and contains the membranes 7a. The descending solids are then collected along the wall of the firebox 2 and fall into the bed 6a located on part or all of the periphery of the firebox 2. A fluidizing gas, such

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as recycled CO<sub>2</sub>, traverses the bed 6a and is mixed with the oxygen released by the membranes 7a, and directly emerges in the firebox 2 without requiring connecting flues.

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We shall now describe the arrangement of the membranes in the bed 6 or 6a.

10 In the variant shown in Figure 3, the membranes 7 are very long and arranged in the length of the bed 6 and secured by intermediate tubesheets 64 which may or may not be cooled. The air enters via the inlet chamber 65 and leaves via the outlet chamber 66.

15 The variants shown in Figures 4 and 5 correspond to a bed 6 in which the membranes 7 consist of short tubes which are placed between the intermediate inlet 65 and outlet 66 chambers arranged in series (Figure 4) or in parallel (Figure 5).

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The variant shown in Figure 6 is a membrane 7 consisting of a support tube 73 surrounded by the membrane tube 74. The air flows inside the support tube 73 comprising openings 73a which enable the oxygen  
25 of the air to be extracted and to traverse the membrane 74.

Figure 12 shows a particular arrangement of the variant shown in Figure 6, in which the two tubes 73  
30 and 74 are spaced in order to allow the air to pass through. They are connected together by spacers 75.

Figure 13 shows an arrangement in which the two concentric tubes 73 and 74 are only open at their ends  
35 730, 731, and 740. The air flows in the direction of the arrow, enters via the end 730 of the tube 73, exits via the other end 731 which communicates with the tube 74, through which the air flows to the end 740 of the tube 74.

In the variant in Figure 7, the membranes 7 are arranged in the bed 6 above the solids 67, and in this case, the fluidizing gas (for example, recycled CO<sub>2</sub>) is heated by the solids 67 and enables the satisfactory operation of the membranes 7 by heating the fluidizing gas to the proper temperature, making it possible to extract the oxygen from the air and remove it.

By combining membranes 7 immersed in the solids and above the solids 67, the membrane area 7 is increased, and hence the potential oxygen production volume, for an identical bed volume.

To arrange additional membranes 7, it is possible to place them on the periphery of the perimeter of the lower firebox 2 (Figure 9) or to create an assembly of them resting on the hearth 20 of the firebox 2 (Figures 10 and 11).

In the variant in Figures 10 and 11, the membranes 7 are placed on the hearth 20 of the firebox 2 which, due to its stiffness, reduces the mechanical stresses applied to the membranes 7, enabling their use in long lengths.